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ABSTRACT

This paper reports a conversation about what constitutes the nature of science (NOS) and what are the best ways to prepare teachers to teach their pupils to understand what it is. The study explores the effects of the explicit teaching of the nature of science in a science education course with a pedagogy component on preservice teachers' conceptions of the NOS and their use of these new conceptions in the design of curriculum units. (KHR)

The Nature of Science as an Academic Discipline and School Subject

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For more than two decades science educators have been involved in a conversation about what constitutes the nature of science (NOS) and what are the best ways to prepare teachers to teach their pupils to understand what it is. Much has already been said about what is the nature of science by scientists, science educators, philosophers, and those engaged in the academic discipline referred to as science studies (Brush, 2000; Eflin, Glennan, & Reisch, 1999; Haraway, 1989; S. Harding, 1986; Kuhn, 1970). Much also has been said about how the NOS can be taught as part of school science (Cobern, Gibson, & Underwood, 1999; P. Harding & Hare, 2000; Ryder, Leach, & Driver, 1999; Smith & Scharmann, 1999). In this study I continue the conversation about the nature of science and the teaching of it by exploring the effects of the explicit teaching of the nature of science in a science education course with a pedagogy component on preservice teachers' conceptions of the NOS and their use of these new conceptions in the design of curriculum units.

Theoretical framework

As both a way to teach NOS and to achieve scientific literacy, reform documents urge teachers to engage their pupils in authentic research activities. The National Science Education Standards (NRC, 1996) includes two content standards that are specific to this study. The first is Science as Inquiry, which states that pupils should understand the nature of science as inquiry and requires that pupils combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their understanding of science. The Content Standards call for pupils to know and understand the history and nature of science as a way to clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures. It can be argued that if these Standards are to be met, teachers need to understand this content and know the teaching methods that facilitate the learning of this knowledge. Few science teachers possess adequate conceptions of the nature of science (Lederman, 1992) and their teaching does not reflect science as done by scientists. Accordingly, their pupils learn science as pre-packaged and delivered knowledge (N. Brickhouse, 1990; Flick, Lederman, & Encohs, 1996; Lederman, 1992)

The NSES Professional Development Standards (NRC, 1996) suggests one way to remedy this situation. They call for science learning experiences for teachers that involve teachers as researchers in scientific inquiry. These experiences should have teachers collecting and analyzing data, and require that they have knowledge of scientific literature, media, and technological resources. However, there is ample evidence in the research literature that these implicit attempts to improve teachers' conceptions of the nature of science are rarely successful (Abd-El-Khalick & Lederman, 2000).

A second way to increase teachers' understanding of the nature of science is to include explicitly the nature of science in pre- and inservice courses. Typically explicit attempts have teachers explore the nature of science by either reading and critiquing the literature on the history, philosophy, or sociology of science, or through study of historical case studies of science being done (Abd-El-Khalick & Lederman, 2000). As with the use of implicit methods, the research reviewed by Abd-El-Khalick and Lederman suggest that even the explicit teaching of the concepts of the nature of science have little impact on teachers' understanding of the domain.

Abd-El-Khalick and Lederman (2000) suggest several reasons for this apparent lack of success in the teaching of the nature of science to teachers. One is that there are two assumptions in the implicit approach that are dependent on a naïve conception of the nature of science. The first assumption is that that the learning of the nature of science is an affective aspect of being a scientist. That is, the nature of science is an attitude or disposition toward the natural world that scientists have. The second is that the way to gain this affective aspect is to engage in science. But what Abd-El-Khalick and Lederman (2000) argue is that this approach ignores the fact that the study of the nature of science is an academic discipline with its own content.

The other reason for the lack of success of the implicit and explicit approaches becomes apparent when one tries to find evidence that teaching has been affected. That is because not only does one need to have expert-like understanding of the concepts of the discipline, it is also necessary for the teacher to know how to teach that discipline. In other words, there is pedagogical content knowledge associated with teaching and learning the nature of science (Abd-El-Khalick & Lederman, 2000). Clearly what this analysis suggests is that attempts should be made to teach the nature of science as a discipline in its own right, and to help teachers to gain the pedagogical content knowledge that they need to teach it to children.

Methods

The setting

In this study preservice teachers were enrolled in a semester-long course on the nature of science. The course was given within the college of education and taught by a professor of science education. There were thirteen students[1] enrolled in the class. Eleven were female and two male. All but two of the students were enrolled in the teacher education program and half had previously taken the science teaching methods course. All of the students had undergraduate majors in the sciences.

The course met once per week for 14 weeks. Each class meeting lasted for 2 1/2 hours. Students were required to read extensively in the literature of the nature of science, including pieces by philosophers, historians, and science educators. Much of the course material was made available to the students on a website. (The URL will be made available in the public in the paper.) Topics included the definition of science, what is meant by scientific literacy, the history of science, women and minorities in science, the teaching of evolution, and curriculum planning and assessment.

There were five main assignments for the course:

1. Reading Questions and Class Participation: A significant part of the course was class discussions of readings assigned for each week. Students were asked to carefully read the assigned readings for each class. Reading questions were assigned each week and were sent by email to the instructor before the next class.
2. Scientists talk about science: Students were required to search the literature to find an article or book by a scientist in which he or she writes about the nature of science. They were then to summarize and critique the scientist's viewpoint in a 3-5 page paper.
3. Stories of discovery: For this assignment students wrote a story of a discovery or a major change in thinking in their science discipline. Part of this assignment was to present the story in a creative manner to the class.

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[1] The author will use "student" to refer to those enrolled in the university course and "pupil" to refer to K12 students. The students in the course use "student" to refer to their pupils.

4. Evolution storyboard: Students developed a "storyboard" for evolution as a small group assignment.
5. Unit plan: Using the model for a unit plan that they used previously in their science teaching methods class, students were required to create a unit plan that had instruction on the nature of science embedded in it.

Data collection and analysis:

A subset of the items from the Views of Science, Technology and Science (VOSTS) (Aikenhead & Ryan, 1992) was used to uncover students' initial understanding of the nature of science. It was also used as a posttest. The other major data source was students' assignments. All of their work except for assignments 4 and 5 was emailed to the instructor and put into a database. Copies of the storyboards and unit plan were kept by the instructor to understand the changes in the students' understanding of the NOS. Predetermined coding categories were developed from a search of the literature on teaching and learning the nature of science. Other coding categories emerged during data analysis. Descriptive statistics were used to understand students' responses to the VOSTS items.

Findings

Only several of the class assignments will be looked at in this paper. They are homework questions about laws and theories, the importance of teaching the nature of science, and how to interact with pupils who support intelligent design creation theories (ID). Two of the larger assignments are also analyzed -- the evolution storyboard and the unit plan.

Laws and theories

One of the first assignments of the course was for students to answer and do the following:

> What is the difference between a scientific theory and a scientific law? Ask two science types or ask pupils in your class if you are in a school system. Report your answers and reflect.

Table 1 summarizes the students' reports. An analysis of their reports indicates that their respondents were evenly split among three different conceptions of what constitutes a scientific theory:

- A theory is a scientific explanation but not proven;
- A theory is tentative and subject to change; and
- A theory is a hypothesis or guess.

One student reported her responses in a way that indicated that her respondents characterized a theory as one of multiple possible explanations. Four of the students indicated their own conception of theory. Two (LF and JM) were inline with how they characterized their respondents' conceptions. A third's (KR) conception disagreed with her pupils', but was inline with her cooperating teacher. In fact in reporting her cooperating teacher's conception, KR wrote, "My cooperating teacher differentiated between the two [theories and laws] more accurately [than her pupils]." The fifth (SB) stated a conception that was more tentative (THG) than that of her respondents (TSE). None of the students suggested that their conception was different from that of their respondents. This suggests that overall the students were describing their own conceptions of what constitutes a scientific theory as well as that of their respondents.

Opinions were much less divided about what constitutes a scientific law. More than 3/4 of the students' characterized their respondents' conceptions as being distinguished from theories because laws are proven. In addition, half of the total stated explicitly that theories become laws when they are proven. In case of laws, all of the students who indicated their beliefs agreed with their respondents that laws are proven. In addition, two of these students also stated explicitly that theories become laws when they are proven.

------------------------- Insert Figure 1 around here -------------------------

At the beginning of the class that this assignment was due, the students were given the definitions of scientific laws, theories and hypotheses found in Figure 1. They then presented what they had found from interviewing "science types" or the pupils in their classes. A discussion followed about the differences between what they had found and the definitions provided by the instructor. Examples of scientific laws (e.g., Boyle's Law, Hooke's Law) were examined as well as examples of scientific theories. In the ensuing discussion the students generally accepted that the definitions provided on the overhead transparencies matched the way that concepts in science were labeled as either theories or laws.

Evolution storyboard

The instructions for the evolution storyboard assignment were simply, "In a small group develop a "storyboard" for evolution." There was some discussion about what constitutes a storyboard, and a standard definition was produced, such as this one: "a set of sketches, arranged in sequence on panels, outlining the scenes that will make up something to be filmed, for example, a motion picture, television show, or advertisement." (Microsoft, 1999) Five sets of students completed the assignment. One of the groups prepared a PowerPoint presentation that depicted macroevolution. Their story was very traditional, even to the point of providing the peppered moth as an example of survival of the fittest. As one might expect from a depiction of the traditional story, they used anthropomorphic language to describe the process. In the instructor's written comments to the group he pointed this out to them and reminded them that "A major point of Darwinian evolution is that it is the result of 'mechanical' random processes and not the result of a creator or even the wills of the animals or plants."

This traditional evolution of life on earth story, similar to the animation that accompanies Stravinsky's *Rite of Spring* in the Disney movie *Fantasia*, was typical to what the instructor had received from students in past years. This was the only group that presented this story. Two of the groups focused on microorganisms. One of these groups had a vocal participant who had worked for several years in Lynn Margolis' lab. Not unexpectedly, the focus of their story was on the evolution of eukaryotic cells. The third group had as its story the microevolution of pathogenic bacteria, including the ways that indiscriminate use of antibiotics serves to select for more resistant pathogens. A fourth group, which consisted of only one student, told the story of the development of the theory of evolution. The remaining storyboard focused on the characteristics of birds that related to their survival. It appears that what they were attempting to do was to illustrate natural selection. However, they did not produce a "story" that sufficiently demonstrated their story line.

Intelligent design

For the week of April 22, students were instructed to read several articles, including one on "intelligent design" that appeared in the *New York Times* (Clines, 2002). The others were articles written by science education researchers (N. W. Brickhouse, Dagher, Letts, & Shipman, 2000; Dagher & BouJaoude, 1997; Rudolph & Stewart, 1998). Students were asked to relate the idea of intelligent design to the ideas about evolution, creationism, and the nature of science found in the science education readings. In addition, they were asked to respond to the following scenario:

> A pupil says to you, "There is no conflict between science and the doctrine of intelligent design because it does not conflict with any laws or theories." How would you respond to this pupil?"

Exemplars from the students' responses to this question and the way that they were coded are in Table 2. Seven of the their responses were based on the assumption that science and theology are different domains and therefore basically orthogonal. However, three of the students say that this causes a conflict, while the others say this results in no conflict. That is, some of the students argued that because ID is not science, it does not conflict with scientific theories like evolution (NCN), while others argued that there is a conflict because ID is not science (CNS). An example of the former is

> Although it might not directly conflict with science law/theories, it still doesn't belong in a science classroom. As Martha Wise put it, "I think ID is a theology, and it belongs in another curriculum."

In this case the student was quoting Martha W. Wise, a member of the Ohio state board of education (Clines, 2002), cited in the New York Times article as an opponent of including ID in the Ohio state science standards.

David Haury, a science educator from Ohio State University, was also quoted in the article: "Science has no statement to make beyond the natural world" and "Intelligent design is about how things got started." (Clines, 2002) One of the students who argued that there is a conflict between science and ID because they are different entities referred to Haury in her reasoning:

> Further, [ID] runs contrary to the NOS. "ID is about how things got started. Evolution is about how they change across time." Creation is not addressed by science. Science is about trying to understand the natural world, not the supernatural world, through observation and experimentation.

Several of the students who saw a conflict between ID and science supported their arguments by referring to the content of evolutionary theory. One argued that the "theory of cumulative selection" can explain the development of a complex organ like the eye and therefore divine intervention is not needed as an explanation. A second stated that because life evolved from simple forms, there was no need to postulate an intelligent designer for complex organisms. The third argued that the implicit assumption in ID that nature is not random is in conflict with the randomness of natural selection. A fourth student based her argument that ID conflicts with science on the nature of science:

> There is a conflict. Science is not about God. Therefore ID does not belong in science. ID does not follow scientific principles and is not widely accepted by the scientific community and therefore is not a theory that should be competing with evolution, which has these characteristics.

Finally, one student was sympathetic to the idea of ID:

> I agree with the pupil. Scientifically we cannot prove, analyze, record data, or even directly observe whether or not an intelligent designer exists. Here we are … how do we explain that? Perhaps an intelligent designer wanted it this way. I think that it's miraculous that we are all here, and great miracles are often disguised as mere coincidence …

Teaching the nature of science

Towards the middle of the semester students were asked the following question: "Is it important to teach the nature of science in the middle or high school level? Why or why not?" Exemplars of their answers and associated codes are found in Table 3. All but one of the students agreed that it is important to teach the nature of science. Their arguments for doing so differed in two significant ways. The first group based their arguments on either the content of the nature of science (history, philosophy and sociology of science) and/or the effects on their pupils of having this knowledge. The second group saw the nature of science as either the methods of science or as a way to help their pupils to become critical thinkers.

The content of the nature of science

Among these students most argued that it was important to understand some aspects of the history, philosophy, or sociology to understand science and its importance for their lives. Below are two examples of this perspective:

It is important to teach it at all levels. This may prove to be a very difficult endeavor, considering that even scientists have a hard time defining what the nature of science is. I think it is important to educate them as to what scientists do and how they look at the world. If the goal of science education is to create effective and competent citizens, then we, as science teachers, really can't afford to not teach students about the nature of science. …

It is important to teach it. So that students have or hopefully gain a better understanding of why we teach science. At the high school level it may be more appropriate to go further in depth about the NOS especially in regards to the connection that learning/thinking about science the way a scientist would. Discussion of the importance of "thinking like a scientist" may help prepare those students who may want to seriously pursue a career in the sciences. In terms of the methodology in teaching the NOS it may be more meaningful to both age groupings to either visit a research facility and/or have a scientist come in and tell about his/her pathway that led his/her to where they are today.

Other students gave the reason that learning the nature of science would better help their pupils to use science in their everyday lives. While this is implicit in the first reason, this second argument does not explicitly refer to the history, philosophy or sociology of science. This can be seen in the following example:

It is important for students to have the opportunity to learn more about science than just factual data. Science should be taught in such a way that the knowledge could be used to solve problems that face us everyday. Everyone should have some appreciation for the workings of science because it is such an integral part of our lives. The process and the meaning of science are just as important as the results of science.

The third reason given within this group was that by understanding the nature of science, pupils would be more attracted to science and possibly make it a career, as these examples show:

It is important. We need to teach students that they too can play a role in the field of science and that it is not something that they should fear.

Yes, for several reasons. Studying the NOS will helps students to see the variety of ways in which they can be a part of science and contribute to it.

The methods of science and critical thinking

For some of the students in the course, the nature of science appeared to be synonymous with the methods of science, as can be seen in the responses of these students:

> All our science lessons should allow students to experience what science is all about. A school year worth of science lessons should include lots of observation, gathering of information, and plenty of experimentation. In this way they can internalize the nature of science while they learn about scientific concepts.
>
> I am now convinced that for a vast majority of students it is more important to learn science process/inquiry skills and how to apply them than to give them lists and lists of facts to memorize that don't encourage them to come up with their own answers. …

In these examples the students are expecting their pupils to learn the methods of science as a means to learning science. Several other students connected the teaching of the methods of science with helping their pupils to become better critical thinkers.

> Yes, for several reasons. Studying the NOS will helps students to think critically about concepts like objectivity and truth. They can think about the advantages and disadvantages of rules, procedures, and laws. … Discussing the NOS will challenge students to consider what they believe.
>
> I believe that trying to teach the nature of science on the high school level is definitely important. By learning about the nature of science, students would foster critical thinking skills that they may apply to other areas, not just in the field of science. These critical thinking skills could help the student later in daily life, whether it was to understand the impact of a recycling program on their own community, or to understand the sorts of choices one must make in order to be a conscientious consumer. Through learning critical thinking, students will also gain a more thorough understanding of what science is about and how it operates.

For these students, teaching the nature of science meant teaching their pupils the *methods* of science. In that sense they equated the nature of science with the methods of science. We will also see this in the next section where the unit plans are discussed.

Finally, it is important to note that at least one student did not think it was important to teach the nature of science explicitly. He put it this way:

> Like I was presented with science, I think other students can be presented with science the same way. As long as the students understand why science occurs the way it does and how it is done, I do not see the necessity of labeling it.

In his answer he was distinguishing between learning the nature of science by doing science from learning it by having it identified and labeled. While this belief was not evident in the other students' responses, it appears from the analysis of the unit plans that this is how most thought about operationalizing the teaching and learning of the nature of science.

Unit plans

The final assignment and assessment for the class was for students to develop a unit plan for a science class that has as one of its objectives the teaching of the nature of science. The instructions for this assignment are in Figure 2. The students worked in four groups and produced unit plans on a variety of topics including an interdisciplinary study of the Hawaiian Islands, global warming, wetland ecosystems, and bacteria and viruses. Two included throughout materials and activities explicitly on the nature of science. A third had explicit instruction about the nature of science in only one portion of the plan. The fourth one did not explicitly teach the nature of science.

------------------------ Insert Figure 2 around here ------------------------

The Hawaiian Islands

Three women students collaborated on this unit plan. In their abstract they wrote:

> The nature of science is discussed explicitly and implicitly throughout the examination of topics such as paradigm shift, scientific method, and the environmental effects of volcanic eruption. The unit ends with a culminating project in which students work on a case study and are also asked to relate their newly gained scientific knowledge to their lives in Massachusetts.

In their rationale for the unit they quote the *National Science Teachers Association* (NSTA) position paper on the nature of science (NSTA, 2000), Thomas Kuhn (1970), and others. The rationale ends with this call to other science teachers:

It is important for people to understand the nature of science if they are to make scientifically informed decisions. Since the nature of science pervades all disciplines and aspects of science, it can easily by incorporated into all science classes. For this reason we encourage science teachers to address the topic with their students.

Of the twenty days of detailed lesson plans, only four have objectives that explicitly refer to some aspect of the nature of science. Two of these focused on the scientific meaning of the terms theory, law, and hypothesis. In addition, one of the two questions for the final assessment again addresses the nature of science:

How do scientific principles and scientific methods construct the way that we use scientific information in our daily lives? (Explain your answer in terms of the information you know about Hawaii. Also consider: Why did we choose Hawaii for this interdisciplinary unit? Could we have chosen a different topic? What makes Hawaii so unique? Is any of the science we discussed also applicable to our life here in Massachusetts?)

Bacteria and viruses

This group of three students consisted of two women and one man. One of the students has had extensive experience working in a biology laboratory on campus that studies prokaryotic organisms. In their abstract they wrote that, "The purpose of this unit plan is to guide students and their teacher through the distinction between bacteria and viruses while teaching the nature of science." In their rationale they explained why they thought learning the nature of science was important if their pupils were to learn about bacteria and viruses:

It has been suggested that through hands on, inquiry based activities, students will learn more effectively. Science allows for this type of instruction through the nature of science. Within the nature of science, students learn how science is performed, how it changes and who performs scientific experiments. Students can learn how scientists perform experiments and model their behavior. By acting like scientists, using experimental procedures, students are actively participating in science, and with this active participation, it is possible that students will better learn science. Furthermore, through the nature of science, the students will learn that anyone can be a scientist, and by helping the students visualize that they can be scientists, it may provoke more interest in the scientific subject being studied.

As one might expect from their rationale, this unit plan has as its goal the teaching of the nature of science through the doing of science, exposure to actual scientists at work, and some references to particular aspects of the nature of science, such as "the different types of stories of discovery as outlined by Donna Haraway and Catherine Milne[2]."

Global warming

The three women who prepared this unit plan described it in this way in their abstract:

> We will teach a unit about global warming and use that topic as a vehicle for exploring the nature of science. We will begin our unit by introducing the concepts of climate, weather patterns, and atmospheric cycles. The next section will concentrate on the greenhouse effect in terms of greenhouse gases and their impact on global warming. The third section will delve into how scientists research global warming.

In their rationale they cite several of the papers and articles that they read for the class (Eflin et al., 1999; Kolsto, 2001; NSTA, 2000). They argue that their pupils will learn the nature of science through their participation in a debate in which they are "required to gather information, judge the validity of the information they read, and defend a position …" This will lead the pupils to realize the "dynamic, tentative, and changing aspects of scientific inquiry."

A close look at the unit plan reveals little attention actually paid to the nature of science, either explicitly, or through the types of activities found in the bacteria and virus unit. One of the reasons for this was that this group did not actually collaborate in the writing of the plan. Instead, they broke it intó three parts, with each student responsible for one part. As a result we find in the first part fairly traditional instruction as evidenced by the beginning of each day's brief description that "I will begin by..."which is followed with the list of terms that the students will learn that day. There also is no evidence of attention paid to the nature of science in either the activities or the curricular objectives for these days. Days 8-13, which were the responsibility of the second student, provide a mix of student-centered, constructivist lessons with teacher presentations. Again, there is no explicit focus on the nature of science in the activities or the

[2] (Haraway, 1986; Milne, 1998)

objectives. Days 14-19, the responsibliity of the third student, is focuses on preparing pupils for the global warming debate. Therefore it has a clearer focus on the nature of science.

Wetland ecosystem

The intent of the fourth group was to teach the nature of science by having their pupils engage in practices similar to those of scientists. This can be seen in the excerpts from their abstract:

> In this unit on discovering wetland ecosystems, students explore scientific concepts in the context of nature, they will be encouraged to think and do as scientists do. Since the underlying focus of the unit is for students to understand the nature of science, students will learn how to use science as a tool to learn important concepts of ecosystems. ... Students will experience for four weeks lessons, activities, lab and field study in which they will practice scientific method during their learning experiences.

This way of conceptualizing the teaching of NOS is made more explicit in their rationale:

> The intention here is that we wish for students to internalize their science experiences to create a sort of "science sense" so that each of our individual students may become knowledgeable, logical, and analytical thinkers, in science, and in life.

Again, an analysis of what is planned in the unit plan for each of its 20 days suggests something very different from the abstract and the rationale. And again, this is partly due to the lack of true collaboration, with now the four students in the group, three women and one man, each taking one week to plan. However, while in the global warming unit there were significant differences in the pedagogy among the three parts, this unit plan uses a potpourri of activities that are typical in middle school science that serve to confirm what is in the "textbooks" rather than being constructivist or inquiry in nature. As a result there was little in the activities or objectives that explicitly related to the nature of science.

VOSTS

As a way to compare what happened in this class with other students, a subset of the items from the Views of Science, Technology and Science (VOSTS) (Aikenhead & Ryan, 1992) instrument was administered to the students as a pre- and post-test. The stems for the items are found in Figure 3. Table 4 shows the stems and possible choices with data from the pre- and post- administration of those items where there was at least some appreciable change. It is important to note that because of the small sample size, no statistical tests seemed appropriate. A careful examination of the data from the VOSTS suggest that either it was not a sensitive enough instrument to uncover the subtleties of students' conceptions of the NOS, or that there was little changed in their beliefs from the beginning to the end of the course. In his current research, the author has found the open-ended questionnaire developed by Lederman and his colleagues (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) provides richer and more useful data.

------------------------ Insert Figure 3 around here ------------------------

------------------------ Insert Figure 4 around here ------------------------

Conclusion and Implications:

One of the outcomes of this close look at students' responses to these assignments is that it becomes clear that their conceptions of what constitutes the nature of science are complex, many-layered, and in flux. This appears to be more so than reported in previous studies. One possible explanation for this is that all of the students in this study have at least an undergraduate degree in one of the sciences, and several have been research assistants in science laboratories or completed theses on scientific topics.

The findings from this study appear to confirm much of what we already know about learning. The analysis of student assignments suggests that students increased their understanding of the nature of science and came to view science as an ill-defined, complex set of human activities. However other data, in particular the unit plans, suggest that there was little change in the students understanding of the NOS. This may be due to what we already know about the transfer of learning across domains. Cognitive studies of learning have suggested that much of learning is domain specific and that it is difficult to transfer cognitive strategies from one domain to another.

One of the arguments that Abd-El-Khalick and Lederman (2000) have made is that the study of the nature of science is a discipline in its own right and therefore should be taught explicitly rather than implicitly as an attitude toward the world. While this study appears to offer evidence that even the explicit teaching of the NOS does not lead to the outcomes called for in the *National Science Education Standards*(NRC, 1996), it is possible that the lack of success is an indicator of the NOS as a discipline. This is supported by arguments about the structure of disciplines made by Joseph Schwab (1978), and of the relationship between school subjects and academic disciplines made by Barbara Stengel (1995). Schwab noted that each academic discipline has substantive and syntactic structures that distinguish it from other disciplines. In the sciences this is apparent in the subject matter and knowledge base of the discipline, and in the rules, both explicit and tacit that govern what counts as legitimate inquiry. If the study of the nature of science is an academic discipline, then it too has a particular set of substantive and syntactic structures that defines it. What this suggests is that there may be no reason to expect any more success with the teaching of the nature of science within a science discipline as we would have teaching literary criticism as part of a science class.

Stengel (1995) has argued that it is important to acknowledge the differences between school subjects and academic disciplines. She has written about three different ways in which the two can be related:

> 1) Academic disciplines and school subjects are essentially continuous; 2) academic disciplines and school subjects are basically discontinuous; 3) academic disciplines and school subjects are different but related in one of three ways -- a) academic discipline precedes school subject, b) school subject precedes academic discipline, or c) that the relation between the two is dialectic (p. 4).

Although there is not enough space in this paper to discuss all the implications of this for the teaching and learning of the nature of science, it is important to note that at this time, a school subject of the nature of science does not exist. This realization suggests that some decisions need to be made as we continue to strive toward goals such as those in the *National Science Education Standards* (NRC, 1996). Is the study of the nature of science important enough to warrant a new school subject? If so, what should be the content of the subject? What measures will we use to determine whether a student has mastered the subject? And, how do we prepare people to teach this discipline?

References:

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving Science Teachers' Conceptions of Nature of Science: A Critical Review of the Literature. *International Journal of Science Education, 22*(7), 665-701.

Aikenhead, G. S., & Ryan, A. G. (1992). The Development of a New Instrument: "Views on Science-Technology-Society" (VOSTS). *Science Education, 76*(5), 477-491.

Brickhouse, N. (1990). Teachers ' Beliefs about the Nature of Science and Their Relationship to Classroom Practice. *Journal of Teacher Education, 41*(3), 53-62.

Brickhouse, N. W., Dagher, Z. R., Letts, W. J., & Shipman, H. L. (2000). Diversity of students' views about evidence, theory and the interface between science and religion in an astronomy course. *Journal of research in science teaching, 37*(4), 340-362.

Brush, S. (2000). Postmodernism versus science versus fundamentalism: An essay review of Science Wars, the Flight from Science and Reason, and The Creation Hypothesis: Scientific Evidence for an Intelligent Designer. *Science Education, 84*(1), 114-122.

Clines, F. X. (2002, February 11). In Ohio School Hearing, a New Theory Will Seek a Place Alongside Evolution. *New York Times*.

Cobern, W. W., Gibson, A. T., & Underwood, S. A. (1999). Conceptualizations of nature: An interpretive study of 16 ninth graders' everyday thinking. *Journal of research in science teaching, 36*(5), 541-564.

Dagher, Z., & BouJaoude, S. (1997). Scientific views and religious beliefs of college students: The case of biological evolution. *Journal of research in science teaching, 34*(5), 429-445.

Eflin, J. T., Glennan, S., & Reisch, G. (1999). The nature of science: A perspective from the philosophy of science. *Journal of research in science teaching, 36*(1), 107-116.

Flick, L. B., Lederman, N. G., & Encohs, L. G. (1996). *Relationship between teacher and student perspectives on inquiry-oriented teaching practice and the nature of science.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Haraway, D. J. (1986). Primatology is politics by other means. In R. Bleier (Ed.), *Feminist approaches to science* (pp. 77-118). NY: Pergamon Press.

Haraway, D. J. (1989). *Primate visions: gender, race, and nature in the world of modern science*. New York: Routledge.

Harding, P., & Hare, W. (2000). Portraying science accurately in classroom: Emphasizing open-mindedness rather than relativism. *Journal of research in science teaching, 37*(3), 225-236.

Harding, S. (1986). *The science question in feminism*. Ithaca, NY: Cornell University Press.

Kolsto, S. D. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science education, 85*(3), 291-310.

Kuhn, T. (1970). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of research in science teaching, 29*(4), 331-359.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of Nature of Science Questionnaire: Toward Valid and Meaningful Assessment of Learners' Conceptions of Nature of Science. *Journal of Research in Science Teaching, 39*(6), 497-521.

Microsoft. (1999). *Encarta® World English Dictionary*

Milne, C. (1998). Philosophically correct science stories? Examining the implications of heroic science stories for school science. *Journal of research in science teaching, 35*, 175-187.

NRC. (1996). *National science education standards*. Washington, DC: National Association Press.

NSTA. (2000). *NSTA Position Statements: The Nature of Science*, from http://www.nsta.org/position

Rudolph, J. L., & Stewart, J. (1998). Evolution and the nature of science: On the historical discord and its implications for education. *Journal of research in science teaching, 35*(10), 1069-1089.

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of research in science teaching, 36*(2), 201-220.

Schwab, J. (1978). Education and the structure of the disciplines. In I. Westbury & N. Wilkof (Eds.), *Science, curriculum, and liberal education: Selected essays [of Joseph J. Schwab]*. Chicago: University of Chicago Press.

Smith, M. U., & Scharmann, L. (1999). Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. *Science education, 83*(4), 493-509.

Stengel, B. (1995, April 18-22). *"Academic discipline" and "school subject": Contestable curricular concepts.* Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.

Figure 1: Transparencies of definitions of Scientific Laws, Theories and Hypotheses

Scientific Laws

Laws are generalizations or universal relationships related to the way that some aspect of the natural world behaves under certain conditions. -- *NSTA Position Paper on the Nature of Science*

Law: A descriptive generalization about how some aspect of the natural world behaves under stated circumstances. -- *Teaching about Evolution and the Nature of Science.*

Law **17. a.** In the sciences of observation, a theoretical principle deduced from particular facts, applicable to a defined group or class of phenomena, and expressible by the statement that a particular phenomenon always occurs if certain conditions be present. -- *Oxford English Dictionary Online*

Theories

Theories are inferred explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories. -- *NSTA Position Paper on the Nature of Science*

Theory: In science, a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses. -- *Teaching about Evolution and the Nature of Science.*

Theory **4. a.** A scheme or system of ideas or statements held as an explanation or account of a group of facts or phenomena; a hypothesis that has been confirmed or established by observation or experiment, and is propounded or accepted as accounting for the known facts; a statement of what are held to be the general laws, principles, or causes of something known or observed. -- *Oxford English Dictionary Online*

Hypotheses

Hypothesis: A testable statement about the natural world that can be used to build more complex inferences and explanations. -- *Teaching about Evolution and the Nature of Science.*

Hypothesis 3. A supposition or conjecture put forth to account for known facts; *esp.* in the sciences, a provisional supposition from which to draw conclusions that shall be in accordance with known facts, and which serves as a starting-point for further investigation by which it may be proved or disproved and the true theory arrived at. -- *Oxford English Dictionary Online*

Figure 2: Instructions for the Unit Plan assignment

Assignment D: Unit plan -- Teaching the Nature of Science. Due May 13th.

This is a cooperative assignment. You will work in groups of 2 or 3 to prepare a complete unit plan.

The complete unit plan will consist of 5 parts: an abstract, rationale for the topic, a list of objectives that include global objectives as well as objectives for traditional content and the nature of science, day-to-day activities, and a final assessment.

Note: Global objectives relate to more universal teaching and learning goals (http://www-unix.oit.umass.edu/~afeldman/globalobjf01.html.)

Make enough copies of the abstract so that you can give a copy to each student in this class. Make two copies of the complete unit plan. One copy will be kept in a file cabinet for reference by other students.

Abstract: Approximately 150 words that briefly describe the unit plan. The purpose is to inform other science teachers about what they would find in the plan that would be useful to them.

Rationale: The rationale should answer the following question -- "Why is it important to study the nature of science?" It should focus on the specific topic rather than more broadly on the subject. The rationale should be an argument in support of the importance of the topic. It should be one typewritten page (about 250-400 words) and include references to articles and books read for this course.

Objectives: List your objectives for this unit. Be complete but do not atomize your list. A significant aspect of the objectives should be a focus on teaching and learning the nature of science. I will look for the manifestation of those objectives in the individual lessons. This requires your group to effectively understand the reasoning behind engaging students in this field of study.

Day-to-day activities: For each of the 20 days, tell both what will be taught (content) and how it will be taught (pedagogy). That is, what you expect to accomplish that day and how you will make that happen. You may want to use the lesson plan format for EDUC 512 (http://www-unix.oit.umass.edu/~afeldman/lessonplanformat.html).
Assessments: Describe how you will assess student learning and determine whether you will have met your objectives for the unit. Include samples of the assessment items.

Figure 3: VOSTS stems

10111 Defining science is difficult because science is complex and does many things. But MAINLY science is:

20411 Some cultures have a particular viewpoint on nature and man. Scientists and scientific research are affected by the religious or ethical views of the culture where the work is done.

40421 In your everyday life, knowledge of science and technology helps you personally solve practical problems (for example, getting a car out of a snowdrift, cooking, or caring for a pet).

40221 Science and technology can help people make some moral decisions (that is, one group of people deciding how to act towards another group of people).

40711 Science and technology influence our everyday thinking because science and technology give us new words and ideas.

60211 The best scientists are always very open-minded, logical, unbiased and objective in their work. These personal characteristics are needed for doing the best science.

60311 A scientist's religious views will NOT make a difference to the scientific discoveries he or she makes.

60311 A scientist's religious views will NOT make a difference to the scientific discoveries he or she makes.

60511 There are many more women scientists today than there used to be. This will make a difference to the scientific discoveries which are made. Scientific discoveries made by women will tend to be different than those made by men.

60532 Male scientists concentrate only on objective ("factual") reasoning. Female scientists ALSO pay attention to subjective ("personal") feelings.

70231 When a new scientific theory is proposed, scientists must decide whether to accept it or not. Scientists make this decision by consensus; that is, proposers of the theory must convince a large majority of fellow scientists to believe the new theory.

70221 When a new scientific theory is proposed, scientists must decide whether to accept it or not. Their decision is based objectively on the facts that support the theory. Their decision is not influenced by their subjective feelings or by personal motives.

70611 With the same background knowledge, two scientists can develop the same theory independently of each other. The scientist's individuality does NOT influence the content of a theory.

70711 Scientists trained in different countries have different ways of looking at a scientific problem. This means that a country's education system or culture can influence the conclusions which scientists reach.

90111 Scientific observations made by competent scientists will usually be different if the scientists believe different theories.

90311 When scientists classify something (for example, a plant according to its species, an element according to the periodic table, energy according to its source, or a star according to its size), scientists are classifying nature according to the way nature really is; any other way would simply be wrong.

90511 Scientific ideas develop from hypotheses to theories, and finally, if they are good enough, to being scientific laws.

90611 When scientists investigate, it is said that they follow the scientific method. The scientific method is:

90631 Scientific discoveries occur as a result of a series of investigations, each one building on an earlier one, and each one leading logically to the next one, until the discovery is made.

90641 Scientists publish the results of their work in scientific journals. When scientists write an article for a journal, they organize their report in a very logical orderly way. However, scientists actually do the work in a much less logical way.

90811 If scientists find that people working with asbestos have twice as much chance of getting lung cancer as the average person, this must mean that asbestos causes lung cancer.

90921 Science rests on the assumption that the natural world cannot be altered by a supernatural being (for example, a deity).

91013 For this statement, assume that a gold miner "discovers" gold while an artist "invents" a sculpture. Some people think that scientists discover scientific THEORIES. Others think that scientists invent them. What do you think?

pre		post		
Freq	percent	Freq	percent	40421 In your everyday life, knowledge of science and technology helps you personally solve practical problems (for example, getting a car out of a snowdrift, cooking, or caring for a pet).
				The systematic reasoning taught in science classes (for example, hypothesizing, gathering data, being logical):
1	9.1	1	7.7	A. helps me solve some problems in my daily life. Everyday problems are more easily and logically solved if treated like science problems.
0	0.0	1	7.7	B. gives me greater knowledge and understanding of everyday problems. However, the problem solving techniques we learn are not directly useful in my daily life.
3	27.3	2	15.4	C. Ideas and facts I learn from science classes sometimes help me solve problems or make decisions about such things as cooking, keeping healthy, or explaining a wide variety of physical events.
3	27.3	6	46.2	D. The systematic reasoning and the ideas and facts I learn from science classes help me a lot. They help me solve certain problems and understand a wide variety of physical events (for example, thunder or quasars).
3	27.3	0	0.0	E. What I learn from science class generally does not help me solve practical problems; but it does help me notice, relate to, and understand, the world around me.
				What I learn from science class does not relate to my everyday life:
0	0.0	0	0.0	F. biology, chemistry and physics are not practical for me. They emphasize theoretical and technical details that have little to do with my day-to-day world.
0	0.0	1	7.7	G. my problems are solved by past experience or by knowledge unrelated to science and technology.
0	0.0	0	0.0	H. I don't understand.
0	0.0	0	0.0	I. I don't know enough about this subject to make a choice.
1	9.1	2	15.4	J. None of these choices fits my basic viewpoint.

pre		post		
Freq	percent	Freq	percent	40711 Science and technology influence our everyday thinking because science and technology give us new words and ideas.
0	0.0	0	0.0	A. Yes, because the more you learn about science and technology, the more your vocabulary increases, and thus the more information you can apply to everyday problems.
0	0.0	1	8.3	B. Yes, because we use the products of science and technology (for example, computers, microwaves, health care). New products add new words to our vocabulary and change the way we think about everyday things.
3	27.3	5	41.7	C. Science and technology influence our everyday thinking BUT the influence is mostly from new ideas, inventions and techniques which broaden our thinking.
				Science and technology are the most powerful influences on our everyday lives, not because of words and ideas:
2	18.2	2	16.7	D. but because almost everything we do, and everything around us, has in some way been researched by science and technology.
4	36.4	0	0.0	E. but because science and technology have changed the way we live.
0	0.0	0	0.0	F. No, because our everyday thinking is mostly influenced by non-scientific things. Science and technology influence only a few of our ideas.
0	0.0	0	0.0	G. I don't understand.
0	0.0	0	0.0	H. I don't know enough about this subject to make a choice.
2	18.2	4	33.3	I. None of these choices fits my basic viewpoint.

pre		post		
Freq	percent	Freq	percent	60211 The best scientists are always very open-minded, logical, unbiased and objective in their work. These personal characteristics are needed for doing the best science.
0	0.0	1	8.3	A. The best scientists display these characteristics otherwise science will suffer.
0	0.0	0	0.0	B. The best scientists display these characteristics because the more of these characteristics you have the better.
4	36.4	6	50.0	C. These characteristics are not enough. The best scientists also need other personal traits such as imagination, intelligence and honesty.
				The best scientists do NOT necessarily display these personal characteristics:
0	0.0	0	0.0	D. because the best scientists sometimes become so deeply involved, interested or trained in their field, that they can be closed-minded, biased, subjective and not always logical in their work.
3	27.3	4	33.3	E. because it depends on the individual scientist. Some are always open-minded, objective, etc. in their work; while others can be come closed-minded, subjective, etc. in their work.
0	0.0	0	0.0	F. The best scientists do NOT display these personal characteristics any more than the average scientist. These characteristics are NOT necessary for doing good science.
0	0.0	0	0.0	G. I don't understand.
1	9.1	0	0.0	H. I don't know enough about this subject to make a choice.
2	18.2	2	16.7	I. None of these choices fits my basic viewpoint.

pre		post		
Freq	percent	Freq	percent	60311 A scientist's religious views will NOT make a difference to the scientific discoveries he or she makes.
3	27.3	3	23.1	A. Religious views do not make a difference. Scientists make discoveries based on scientific theories and experimental methods, not on religious beliefs. Religious beliefs are outside the domain of science.
2	18.2	3	23.1	B. It depends on the particular religion itself, and on the strength or importance of an individual's religious views.
				Religious views do make a difference:
0	0.0	1	7.7	C. because religious views will determine how you judge science ideas.
4	36.4	1	7.7	D. because sometimes religious views may affect what scientists do or what problems they choose to work on.
0	0.0	0	0.0	E. I don't understand.
0	0.0	0	0.0	F. I don't know enough about this subject to make a choice.
2	18.2	5	38.5	G. None of these choices fits my basic viewpoint.

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pre		post		
Freq	percent	Freq	percent	60511 There are many more women scientists today than there used to be. This will make a difference to the scientific discoveries which are made. Scientific discoveries made by women will tend to be different than those made by men.
				There is NO difference between female and male scientists in the discoveries they make:
2	16.7	2	15.4	A. because any good scientist will eventually make the same discovery as another good scientist.
0	0.0	0	0.0	B. because female and male scientists experience the same training.
0	0.0	0	0.0	C. because overall women and men are equally intelligent.
0	0.0	0	0.0	D. because women and men are the same in terms of what they want to discover in science.
0	0.0	0	0.0	E. because research goals are set by demands or desires from others besides scientists.
0	0.0	0	0.0	F. because everyone is equal, no matter what they do.
4	33.3	2	15.4	G. because any differences in their discoveries are due to differences between individuals. Such differences have nothing to do with being male or female.
2	16.7	5	38.5	H. Women would make somewhat different discoveries because, by nature or by upbringing, females have different values, viewpoints, perspectives, or characteristics (such as sensitivity toward consequences).
0	0.0	0	0.0	I. Men would make somewhat different discoveries because men are better at science than women.
0	0.0	0	0.0	J. Women would likely make somewhat better discoveries than men because women are generally better than men at some things such as instinct and memory.
0	0.0	1	7.7	K. I don't understand.
1	8.3	0	0.0	L. I don't know enough about this subject to make a choice.
3	25.0	3	23.1	M. None of these choices fits my basic viewpoint.

Pre		post		
Freq	percent	Freq	percent	70711 Scientists trained in different countries have different ways of looking at a scientific problem. This means that a country's education system or culture can influence the conclusions which scientists reach.
				The country DOES make a difference:
3	27.3	3	23.1	A. because education and culture affect all aspects of life, including the training think about a scientific problem.
0	0.0	1	7.7	B. because each country has a different system for teaching science. The way scientists are taught to solve problems makes a difference to the conclusions scientists reach.
0	0.0	2	15.4	C. because a country's government and industry will only fund science projects that meet their needs. This affects what a scientist will study.
1		2	15.4	D. It depends. The way a country trains its scientists might make a difference to some scientists. BUT other scientists look at problems in their own individual way based on personal views.
				The country does NOT make a difference:
2	18.2	3	23.1	E. because scientists look at problems in their own individual way regardless of what country they were trained in.
1	9.1	0	0.0	F. because scientists all over the world use the same scientific method which leads to similar conclusions.
0	0.0	0	0.0	G. I don't understand.
1	9.1	0	0.0	H. I don't know enough about this subject to make a choice.
2	18.2	2	15.4	I. None of these choices fits my basic viewpoint.

pre		post		
Freq	percent	Freq	percent	90921 Science rests on the assumption that the natural world cannot be altered by a supernatural being (for example, a deity).
				Scientists assume that a supernatural being will NOT alter the natural world:
2	18.2	5	38.5	A. because the supernatural is beyond scientific proof. Other views, outside the realm of science, may assume that a supernatural being can alter the natural world.
2	18.2	0	0.0	B. because if a supernatural being did exist, scientific facts could change in the wink of an eye. BUT scientists repeatedly get consistent results.
2	18.2	0	0.0	C. It depends. What scientists assume about a supernatural being is up to the individual scientist.
2		2	15.4	D. Anything is possible. Science does not know everything about nature. Therefore, science must be openminded to the possibility that a supernatural being could alter the natural world.
0	0.0	0	0.0	E. Science can investigate the supernatural and can possibly explain it. Therefore, science can assume the existence of supernatural beings.
0	0.0	0	0.0	F. I don't understand.
0	0.0	0	0.0	G. I don't know enough about this topic to make a choice.
3	27.3	6	46.2	H. None of these choices fits my basic viewpoint.

pre		post		
Freq	percent	Freq	percent	91013 For this statement, assume that a gold miner "discovers" gold while an artist "invents" a sculpture. Some people think that scientists discover scientific THEORIES. Others think that scientists invent them. What do you think?
				Scientists discover a theory:
1	10.0	2	16.7	A. because the idea was there all the time to be uncovered.
0	0.0	1	8.3	B. because it is based on experimental facts.
0	0.0	0	0.0	C. but scientists invent the methods to find the theories.
1	10.0	2	16.7	D. Some scientists may stumble onto a theory by chance, thus discovering it. But other scientists may invent the theory from facts they already know.
				Scientists invent a theory:
4	40.0	2	16.7	E. because a theory is an interpretation of experimental facts which scientists have discovered.
2	20.0	2	16.7	F. because inventions (theories) come from the mind — we create them.
0	0.0	0	0.0	G. I don't understand.
0	0.0	0	0.0	H. I don't know enough about this topic to make a choice.
2	20.0	3	25.0	I. None of these choices fits my basic viewpoint.

Table 1: Data from theory/law assignment.

Theories:

Informant	Exemplar	Code	
6th graders summarized (KR)	A scientific theory is little more than an "educated guess," a hypothesis or prediction.	THG	
Businessman (SB)	A theory is a drawn out hypothesis -- a detailed explanation not yet proven or disproved	THG	
Science person 2 (JB)	Theories are the questions that scientists use during the experimental process to discover a law.	THG	
School students (TC)	A scientific theory is a hypothesis or idea that is not definite yet or not proven.	THG	
Summary (KB)	A scientific theory is a proposed hypothesis to explain a scientific situation that has yet to be proven.	THG	
Chemistry teacher (SB)	A theory is something yet to be proven by scientific investigation.	THG	
Non-science adult (BL)	Theory is a perspective that may or may not be proved but multiple perspectives are allowed.	TMP	
Environmental educator (LD)	A theory is a hypothesis or group of hypotheses that have been repeatedly confirmed by experiments.	TSC	
Chem teacher (BL)	Scientific theories are ideas of how things work but not completely proven	TSE	
Cooperating teacher (KR)	A proposition to a law that has not yet been proven	TSE	
Summary (LS)	A theory is an interpretation of a law, a model.	TSE	
Summary (LF)	A theory is a hypothesis of an explanation for a series of observations	TSE	
Environ'ist (JM)	A scientific theory is more of a hypothesis	TSE	
Physicist (JM)	A scientific theory is more of a hypothesis because it can be tested	TSE	
Summary (LK)	A theory may be true or false.	TSE	
Pol scientist (TC)	A scientific theory needs more testing to become a law.	TSE	
Chemistry prof (TC)	A theory is just a theory; it has not been tested to the fullest extent of human capabilities.	TSE	
Scientist (SB)	A theory is based on science but no one is absolutely certain that it is true.	TSE	
Dave (JBe)	A scientific theory requires further experimentation to become a law	TSE	T→L
Charlene (JBe)	A theory needs proof to become a law	TSE	
Biologist (BL)	A scientific theory could not be proven whereas a scientific law could be proven.	TTS	
Environmental educator (LD)	In a theory there is always the possibility that it will be disproved or falsified.	TTS	
Summary (RW)	A scientific theory is an idea that is widely accepted by scientists but not proven beyond a doubt.	TTS	
Science person 1 (JB)	A scientific theory was a statement that consistently described some natural phenomenon, and may have evidence to support it, but has not been tested enough to become a law.	TTS	T→L

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Laws

Informant	Exemplar	Code	
Biologist (BL)	A scientific theory could not be proven whereas a scientific law could be proven.	LAP	
Cooperating teacher (KR)	A fundamental principle that follows the laws of nature; a law that has been proven.	LAP	T→L
Summary (LF)	A scientific law is a theory that has been proven year after year as people see it as fact.	LAP	T→L
Environmentalist (JM)	A scientific law is a theory that has been tested over and over again and withstood those tests	LAP	T→L
Physicist (JM)	A law is a theory that has stood the test of time	LAP	T→L
Summary (LK)	A law has never been proven false. There is some consensus of its validity in the scientific community. Theories that are consistently true and agreed upon become laws.	LAP	T→L
School studs (TC)	A scientific law is proven and is therefore always right/true.	LAP	
Political scientist (TC)	A scientific law is something that has been proven	LAP	
Chemistry prof (TC)	A scientific law is a theory or hypothesis that has had substantial testing. It has not been proven incorrect.	LAP	T→L
Summary (KB)	One a theory has been proven, it becomes a law.	LAP	T→L
Chemistry teacher (SB)	A law was once a theory and is provable by scientific experiment	LAP	T→L
Scientist (SB)	A scientific law is so tested that is absolutely true and clear-cut.	LAP	
Businessman (SB)	A scientific law is a scientific theory that is thought proven and generally accepted by the scientific community.	LAP	T→L
Summary (RW)	A scientific law is an idea or paradigm that has been proven and accepted as true. A theory can become a law.	LAP	T→L
Science person 1 (JB)	A scientific law was a theory that had been observed and tested so completely that it is relatively absolute.	LAP	
Dave (JBe)	A scientific law has been subjected to extensive experimentation and proven valid every time	LAP	
Charlene (JBe)	Law was probably once a theory that has been proven over time.	LAP	T→L
Chem teacher (BL)	Scientific laws are things that always work	LAT	
Environmental educator (LD)	A law is a big thing of science that cannot be disproved or falsified.	LAT	
6th grade students summarized by (KR)	An actual rule or a statement that exists in science She also agrees with her cooperating teacher	LAT	
8th grade class	No scientific understanding of the terms	LNU, TNU	
Non-science adult (BL)	Laws have been defined, although not absolute truth, and may be in part a theory	LST	
Science person 2 (JB)	Theories are the questions that scientists use during the experimental process to discover a law.	LST	
Non-scientist (JB)	Laws and theories are the same type of thing	?	
Summary (LS)	A law is a principle.	?	

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Students' definitions

Informant	Exemplar	Code	
KR	Meaning that a theory is something that has yet to be accepted as of part of scientific knowledge base without further tests and studies.	TSE	
LF	A scientific theory is more of a hypothesis	TSE	
JM	A theory can never be proven true. It is more than a hypothesis because it has been tested and remains true.	TSE	
SB	A scientific theory is an in-depth hypothesis that is neither wrong nor right and hasn't been tested.	THG	
LF	Scientific law is a theory that has been proven	LAP	T→L
SB	A scientific law was once a theory that has been tested many times	LAP	T→L
JM	A law either has been or has the potential to be proven true.	LAP	

Codes:
LAP -- Laws are proven.
LAT -- Laws are always true.
LNU -- Little understanding of what is meant by "theory" either in scientific or everyday terms.
LST -- Laws are stronger theories.
THG -- Theory is a hypothesis or guess.
TMP -- Theory is one of multiple possible explanations.
TNU -- Little understanding of what is meant by "theory" either in scientific or everyday terms.
TSC -- Theory is scientific explanation, confirmed.
TSE -- Theory is scientific explanation, but not proven.
TTS -- Theory is tentative, subject to change.

T→L -- Theories become laws.

Table 2: Students' responses to hypothetical conversation with their students about ID.

Student	Exemplar	Code
LS	The doctrine of intelligent design (ID) does conflict with scientific theories. [Gives example of how the evolution of the eye does not require divine intervention with the "theory of cumulative selection."]	CGR
JM	ID does conflict with evolutionary theory in that it disputes the idea of randomness of natural selection. By arguing that nature is not random, that is was designed by an intelligent being, natural selection [defined by JM] is falsified by ID theory.	CGR
KN	It does conflict. Laws and theories are not fact, but only an interpretation of what is observed and thought to have occurred. ID says that God created the organisms on Earth in a complex manner that nature would not be able to design. From a scientific position, organisms on earth have evolved from a single life form. It was not placed on Earth in a complex form as is believed by ID.	CGR
LK	There is a conflict. Science is not about God. Therefore ID does not belong in science. ID does not follow scientific principles and is not widely accepted by the scientific community and therefore is not a theory that should be competing with evolution, which has these characteristics.	CGR
JM	Further, [ID] runs contrary to the NOS. [Quoting Haury] "ID is about how things got started. Evolution is about how they change across time." Creation is not addressed by science. Science is about trying to understand the natural world, not the supernatural world, through observation and experimentation.	CNS
SB	I would respond to this student by asking them if he/she knew what a law or theory was. If they didn't clearly know what either was then there would be lessons regarding law vs. theory, the use of the words in everyday language vs. scientifically. Also part of the class discussion would be about how students think that a law automatically becomes a theory which is false. Students would then carry out an investigation to gain a better understanding about what a theory consists of in the scientific community - that there needs to be data and evidence for that theory to exist. They would then compare the Intelligent Design Theory and the Theory of evolution to see the word theory is applied according to what the scientific community deems a theory a theory.	CNS
KR	There is a conflict because they are separate entities. Each religion forms its own doctrines of creation, and hold fast to them as their beliefs on the origins of life. Whereas, science involves the scientific theory of evolution that deals which adaptations in organisms over time that is supported by evidence.	CNS
JBe	I agree with the student. Scientifically we cannot prove, analyze, record data, or even directly observe whether or not an intelligent designer exists. Here we are … how do we explain that? Perhaps an intelligent designer wanted it this way. I think that it's miraculous that we are all here, and great miracles are often disguised as mere coincidence …	NCI
BL	Although it might not directly conflict with science law/theories, it still doesn't belong in a science classroom. As Martha Wise put it, "I think ID is a theology, and it belongs in another curriculum." [It may be a good idea to have a debate in science class as to whether it does belong in science.]	NCN
RW	It does not conflict because ID is not a scientific theory. It is not based on data or observation, and is not taught in science class. Having belief in ID does not necessary conflict with science. All aspects of science can be accepted and understood while still believing in the presence of a higher power.	NCN
LD	Does not conflict because the first part of scientific theory is a hypothesis that is designed to ask the question in a sense science is a way to answer that question, intelligent design in a sense doesn't follow this pattern despite it doesn't break any law or theory.	NCN
LK	There isn't a conflict. [Quoting Haury] "ID is about how things got started. Evolution is about how they change across time."	NCN

CGR -- ID conflicts and student gives a scientific reason.
CNS -- ID conflicts because ID does not fit the NOS.
NCI -- There is no conflict because ID can't be proven/disproved with science.
NCN -- There is no conflict because ID isn't science.

Table 3: Students' opinions about teaching the nature of science

Student	Exemplar	Code
JBe	Students should be encouraged to be scientifically creative; to question, hypothesize, to design their own experiments, take and analyze their own data, and draw conclusions.	ICT
LK	Yes, for several reasons. Studying the NOS will helps students to think critically about concepts like objectivity and truth. They can think about the advantages and disadvantages of rules, procedures, and laws. ... Discussing the NOS will challenge students to consider what they believe.	ICT
JB	I believe that trying to teach the nature of science on the high school level is definitely important. By learning about the nature of science, students would foster critical thinking skills that they may apply to other areas, not just in the field of science. These critical thinking skills could help the student later in daily life, whether it was to understand the impact of a recycling program on their own community, or to understand the sorts of choices one must make in order to be a conscientious consumer. Through learning critical thinking, students will also gain a more thorough understanding of what science is about and how it operates.	ICT
LD	I haven't decided exactly what the nature of science is. From what I read so far there isn't even consensus among philosophers, scientists, and educators as to what the nature of science is or should do. I think to a certain level we should teach the nature of science as it is premised in the NSTA in HS for at least some basic understanding. (Although, I don't like the last disconnected premise.) In middle school, I think there should be more application type lessons rather then teaching an actual core of the nature of science.	INR
BL	It is important. We need to teach students that they too can play a role in the field of science and that it is not something that they should fear.	IOS
LK	Yes, for several reasons. Studying the NOS will helps students to see the variety of ways in which they can be a part of science and contribute to it.	IOS
JB	Learning about the nature of science would help students to develop a more open attitude toward science. This would prevent students from becoming alienated from science, as they see how science is an extremely social endeavor that has relevance to their daily lives. Most importantly, teaching the nature of science would give students a more accurate view of scientists, their work, and how they are influenced by everything around them.	IOS
JBe	Certainly!! All our science lessons should allow students to experience what science is all about. A school year worth of science lessons should include lots of observation, gathering of information, and plenty of experimentation. In this way they can internalize the nature of science while they learn about scientific concepts.	MOS
BL	It is important. I am now convinced that for a vast majority of students it is more important to learn science process/inquiry skills and how to apply them than to give them lists and lists of facts to memorize that don't encourage them to come up with their own answers. ...	MOS
KB	Like I was presented with science, I think other students can be presented with science the same way. As long as the students understand why science occurs the way it does and how it is done, I do not see the necessity of labeling it.	NIE
KR	Important because science is a way of knowing and observing the natural world. ... With this knowledge, students will gain an interpretation of scientific disciplines, based on scientific inquiry rather than simply scientific "fact."	NOS
BL	It is important to teach it at all levels. This may prove to be a very difficult endeavor, considering that even scientists have a hard time defining what the nature of science is. I think it is important to educate them as to what scientists do and how they look at the world. If the goal of science education is to create effective and competent citizens, then we, as science teachers, really can't afford to not teach students about the nature of science. ...	NOS
LK	Yes, for several reasons. Discussing the NOS and its evolution through time will give them a historical context for some of the things they might be studying in science class.	NOS
LF	I think it is important to teach the nature of science to student in middle school and high school. It is important for students to understand the basic constitutions/essence of sciences and may best be learned in conjunction with the knowledge and methods of inquiry, etc. related to specific scientific disciplines.	NOS

LS	I think it is important for students to explore the nature of science on their own by giving them more leeway in their experimental processes, as opposed to teaching [didactically?] the nature of science. ... If I had been taught that science is "reliable and tentative" or that laws and theories that have some factual component are not necessarily "true," I might have questioned the validity of doing science.	NOS
JBe	Students should understand theories and laws and how those conclusions were drawn. If they understand how and why scientific concepts are what they are, then they will be likely to have confidence in scientific knowledge, that scientific knowledge is valid, logical and sensible. Students should be able to develop confidence with their own scientific thought and ultimately, use this nature of thinking to develop more confidence in their everyday way of thinking.	NOS
LK	Yes, for several reasons. Understanding the NOS will help students see the larger picture of what science is all about. It will help them grasp that science is more than just lab experiments, the scientific method, or the periodic table of elements.	NOS
JM	I believe that it is important to teach the nature of science in high school but I am not convinced that it needs to be or should be taught in middle school. ... I think that after three or four years of the scientific method being drilled into students, it is appropriate to discuss why we use it. ... It might even spark interest in science in students who normally find science intimidating. Suddenly, they would be able to see why they are in the class, what they should take away from the class at the end of the year, and how history and philosophy are involved in science.	NOS
SB	It is important to teach it. So that students have or hopefully gain a better understanding of why we teach science. At the high school level it may be more appropriate to go further in depth about the NOS especially in regards to the connection that learning/thinking about science the way a scientist would. Discussion of the importance of "thinking like a scientist" may help prepare those students who may want to seriously pursue a career in the sciences. In terms of the methodology in teaching the NOS it may be more meaningful to both age groupings to either visit a research facility and/or have a scientist come in and tell about his/her pathway that led his/her to where they are today.	NOS
TC	We should start teaching [the NOS] at the high school level because student will be able to grasp to complexity of the nature of science. It is important for students to understand why, what, and the importance of science. Also it is important for students to be able to use science and in their every day life not just as scientist. Understanding the nature of science will help students in this process.	SEL
RW	It is important for students to have the opportunity to learn more about science than just factual data. Science should be taught in such a way that the knowledge could be used to solve problems that face us everyday. Everyone should have some appreciation for the workings of science because it is such an integral part of our lives. The process and the meaning of science are just as important as the results of science.	SEL

Codes
ICT -- NOS is important to teach for critical thinking.
INR -- NOS is important to teach no reason.
IOS -- NOS is important to teach for students to see themselves as scientists.
MOS -- NOS is important because teaching it is the teaching of scientific methods.
NIE -- It is not important to teach the NOS explicitly.
NOS -- Teaching the NOS is important because it is the philosophy, history and the social sciences of science.
SEL -- Science in everyday life

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